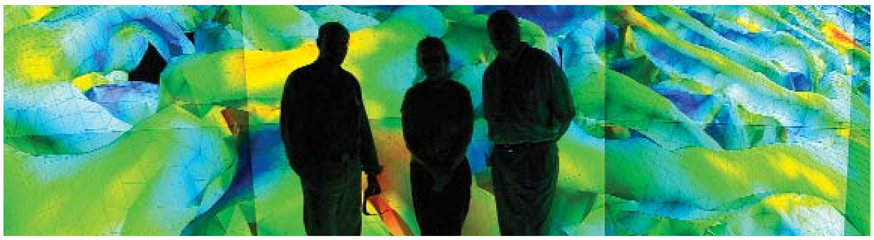
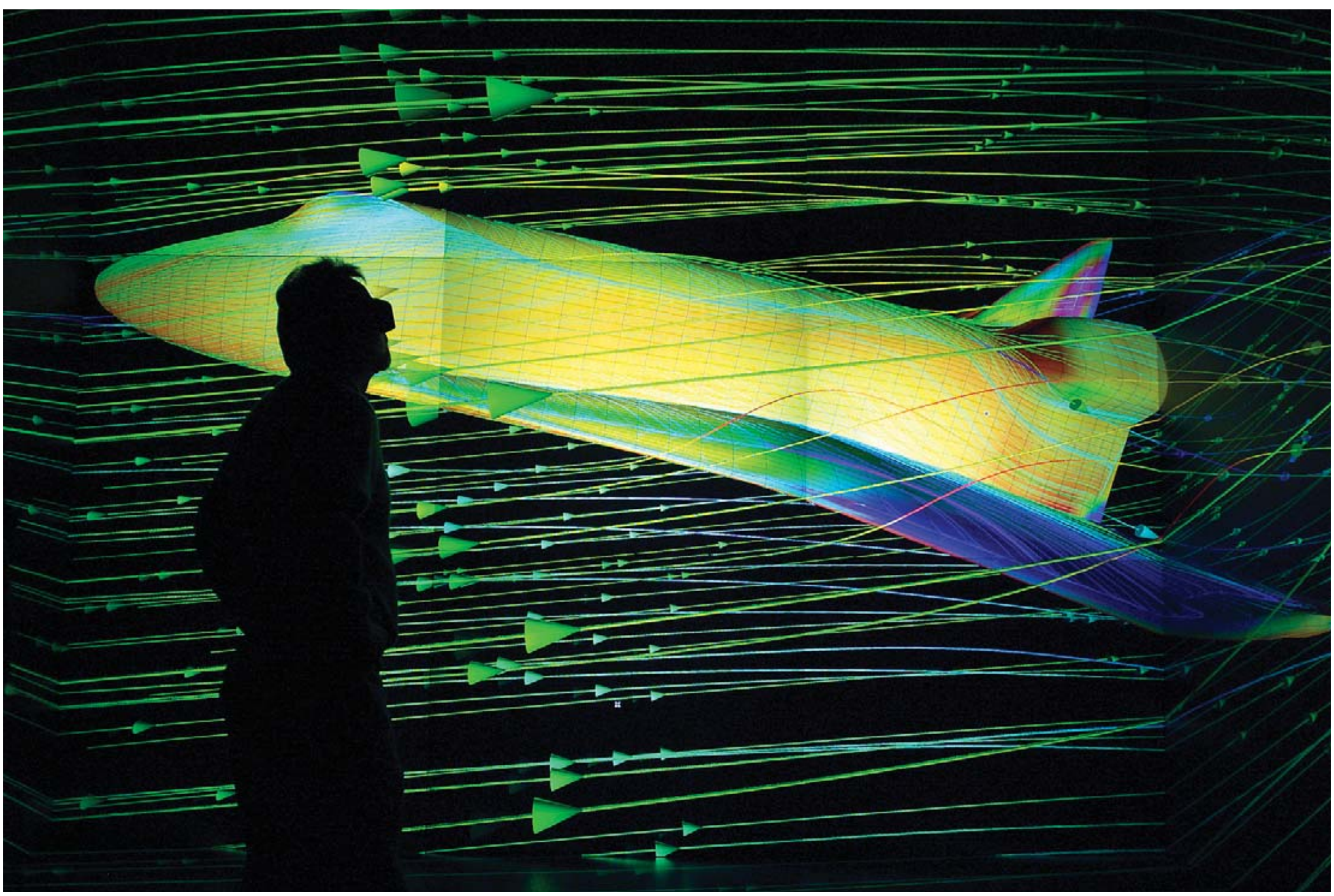
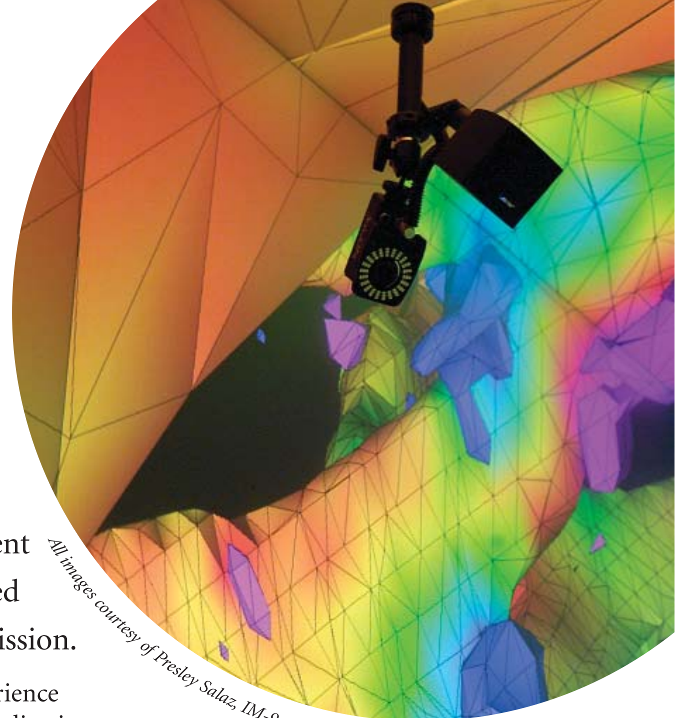
EXTREME RESOLUTION VISUALIZATION ENABLES NEW DISCOVERIES



Advancing the nature of predictive simulation science





All images courtesy of Presley Salaz, IM-9, Los Alamos National Laboratory

Laura Monroe, Steve Stringer and Jeff Brum

LOS ALAMOS NATIONAL LABORATORY (LANL) IN Los Alamos, NM, has been using advanced visualization to solve complex problems since the late 1990s. Funded under the direction of the U.S. National Nuclear Safety Administration, its mission is to maintain the U.S. government nuclear stockpile without underground testing. The Advanced Simulation and Computing (ASC) Program supports this mission.

Over the past few years, the LANL Data Visualization Corridor (DVC) was developed to enable detailed visual inspection, analysis, verification and validation of terascale computing simulations. The DVC includes a variety of tiled PowerWall Theaters, a five-sided Immersive Laboratory, more than 50 desk-based immersive systems, and the prototype of what is now known as the Fakespace FLEX reconfigurable immersive display.

These systems have proven the value of large-scale visualization and virtual reality applications in the analysis of massive amounts of data. With the DVC in place, more than 50 Los Alamos scientists and engineers can work at their desks, or can simply walk down the hallway from their offices at the Nicholas C. Metropolis Center for Modeling and Simulation, to use a system that enables them to log into their familiar user environment on the host computer and immediately visualize high-resolution, large-scale data with the option of collaborating in a group for detailed exploration, analysis and peer review.

The challenge

The ASC Program at Los Alamos National Laboratory creates single simulations that can generate as many as 652 terabytes of data. The challenge was for researchers to create an interface that enables humans to understand and analyze the highly detailed structures in such enormous datasets. The ASC team used its experience with existing large-scale visualization systems to develop the requirements for a new facility, with increased resolution to more effectively visualize the phenomena and simulations generated by the national laboratories' network of supercomputers, including a Los Alamos system with 80 processors and 80 gigabytes of memory.

Defining system requirements

The development team visited other sites known for their state-of-the-art multi-panel display systems, including the Beckman Institute at the University of Illinois at Urbana, and the Electronic Visualization Lab at the University of Illinois at Chicago, where the original CAVE, a fully immersive virtual reality room, was developed.

The solution had to conform to the standards of the Data Visualization Corridor to ensure ease-of-use for scientists already familiar with the system. This required integration of both older and brand-new computing platforms with the existing video distribution system and visualization software used at the other large-scale simulation environments at Los Alamos.

The major choices made were in the areas of resolution, projectors and facility shape. Although the six-sided facilities viewed provided excellent immersion, an audience area was desired, hence the requirement for a five-sided facility. Appropriate resolu-

Clockwise from bottom left, opposite:
▶ A high resolution display makes it easy to understand how aerodynamics impact the space shuttle. ▶ Pictured from left to right are Bob Greene, X-3, Katharine Chartrand, CCN-8, and Bob Kares, X-3, all from LANL. ▶ A camera tracks movement so that visualizations in La Cueva Grande are always in correct perspective for the primary viewer; realistic motion parallax enhances the experience.

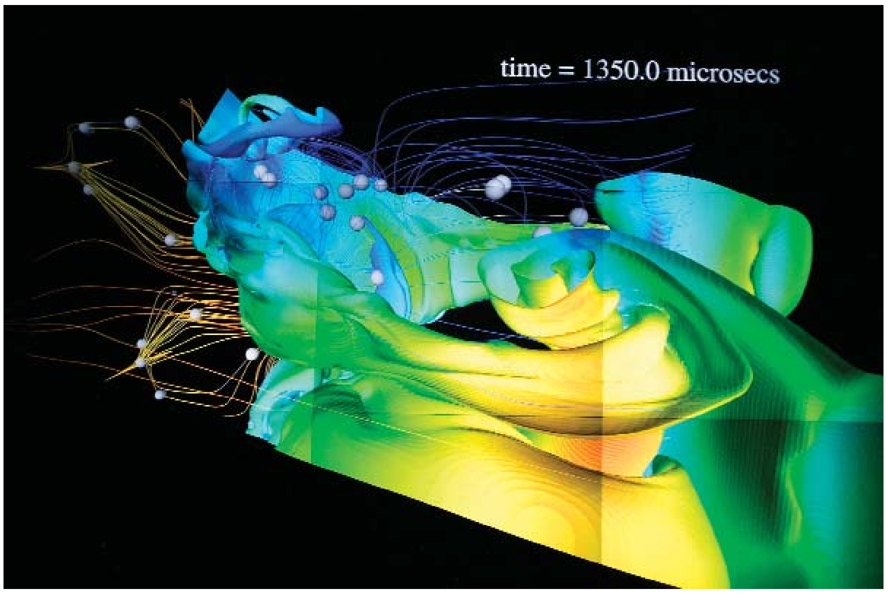
tion was debated for some time; because of the detailed nature of the simulations studied in this facility, high resolution was desired, within the parameters of room size and cost. In the end, a facility comprising 33 projectors was decided upon, giving a resolution of 43 million pixels and a density of 21 pixels per linear inch. Finally, the digital projectors were chosen, as giving much better dynamic range of colors and better brightness and contrast than the old CRT projectors.

After working with visualization environments for a number of years, Los Alamos researchers have found that an immersive environment, involving large screens to fill peripheral vision, and stereoscopic projection for a real sense of three-dimensional space, engages more parts of the brain to understand problems and solve them faster.

The ASC program is tasked with stockpile stewardship. In order to understand the nature of the problem, one can refer to a metaphor from the automobile industry. Imagine that engineers are tasked to ensure that a 25-year-old racing car is to be put into storage for an indefinite period, and its "user" must be kept in constant assurance that the vehicle will be ready for use at any time. The catch: it can never actually be started up or test-driven while in storage.

So the task is to model and simulate the critical system(s) that guarantee operational readiness. For instance, the engine: if this were an ASC problem, the scientists and engineers would collaborate to model in excruciating detail the physical geometry of the engine itself, the mechanical operation of the constituent parts, and the fundamental physics of the fuel-air mixture as it explodes and drives the pistons, plus the lubricating and cooling qualities of the oil and the coolant as it circulates, and so on. Also, questions might arise as the vehicle sits in storage for year after year. What's happening to the hoses, belts, gaskets and plastic parts? Is the gasoline evaporating inside the fuel line and the carburetor? Is the oil maintaining its lubricating characteristics? Any of these issues and dozens of others could arise, resulting in additional modeling and simulation requirements. These in turn drive the degree of modeling resolution and detail needed to arrive at a sufficient level of certainty regarding the fundamental question: Will this old race car start instantly and perform per specification, wherever and whenever that might be?

So CAD models, finite element modeling, materials modeling and phenomenological modeling based on physical first principals all play a part in the simulations needed to satisfy these requirements. For a sense of scale, consider what small cracks in the cylinder head gasket might do to constrain engine performance. How do they form? How big are they? How many are there? These and other issues drive the ASC scientists to model the entire physical system down to below sub-millimeter resolution. Likewise, if questions arise concerning the fuel-air mixture or the characteristics of its ignition, simulation time-slices often are measured at below $1/10{,}000^{th}$ of a second — and the simulations will run for thousands of time slices.



WHEN VIEWED IN THE IMMERSIVE room, researchers can better understand phenomena such as this three-dimensional hydrodynamic simulation, showing the interface between two gasses of different densities.

Los Alamos researchers divide the visualization process into four stages, starting with insight and discovery, followed by debugging and data validation. In the debugging stage, data accuracy down to the minutest detail is important in finding errors in the complex meshes that are visualized. For example, one white pixel when all the others are red could indicate an error, or an important phenomenon. Stereo viewing with an extremely large field of view and very sharp and precise detail is essential for this level of analysis. An extremely high-resolution display is required to eliminate the artifacts that are sometimes generated at lower resolutions, and that can have a major impact on data interpretation.

Obviously, these operational requirements will result in large amounts of raw data — demonstrably more in one job than is contained in the entire print collection of the Library of Congress. Making meaningful sense of all this data in a reasonable timeframe is the role of the advanced visualization tools employed in the DVC. LANL's use of the technology has demonstrated that several visualization primitives are key to successful utilization. Large physical size, high resolution everywhere, 3-D stereo everywhere, high contrast, bright images, motion and animation, real-time interfaces and controls, and more, all must be integrated in order to achieve end-user engagement. Further lowering barriers to use includes keeping the end-users' environment familiar, maximizing the ease of use of facility-specific controls, embedding the facilities nearby to users' offices, delivering sufficient lighting, viewing, and seating comfort levels, all which must be managed towards a practical end goal of keeping the technology from getting in the way of the engineers' and scientists' thought processes.

The solution

To make the best use of the huge amounts of data produced by the ASC program, Los Alamos researchers worked with Iowa-based Fakespace Systems to design and build the world's highest resolution, walk-in immersive viewing environment, providing a 43 million-pixel display. Formally titled the "Immersive Laboratory," LANL researchers colloquially refer to this system as "La Cueva Grande."

The Cueva Grande system is a 15-ft. wide by 10-ft. deep and 12-ft. high room in which images are rear-projected onto three walls, the ceiling and the floor. A total of 33 stereoscopic digital projectors are seamlessly tiled to produce continuous images that meet rigorous requirements for brightness, resolution and dynamic color range, so that small details and subtle phenomena can be easily detected and analyzed.

Los Alamos chose a five-sided immersive room over a completely enclosed, six-walled room. The five-sided design, including a rear-projected floor and ceiling, is more comfortable for long periods of use.

Software and systems

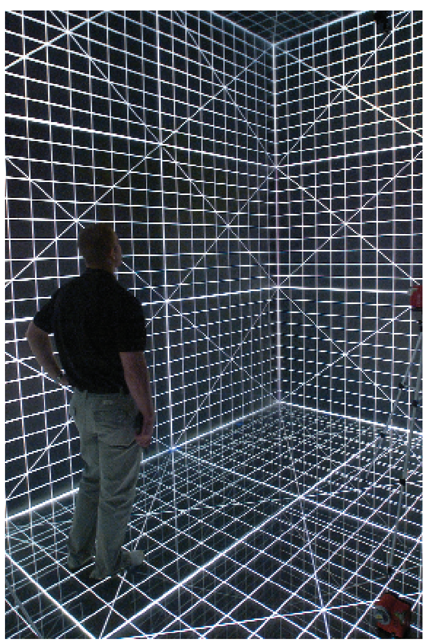
CEI EnSight software, for three-dimensional scientific visualization, is fully integrated into the immersive room and is used as a standard platform throughout the ASC facility. While users can work with a standard mouse and keyboard in the visualization room, EnSight also allows motion tracking and physical interaction with simulations using a glove interface and a stylus.

The software runs on a special SGI Onyx4 3900 supercomputer, which is configured with 34 graphics engines (or pipes) so that all 33 projectors display one integrated stereoscopic image that changes in real time with the users' movement. Each projector is an active stereo three-chip DLP system providing native 1280 x 1024 pixel density with 2,000 ANSI lumens brightness.

Extreme resolution

It is typical at Los Alamos that a large three-dimensional problem may have as many as 500 million cells with tens of variables per cell. A single time step dump from such a problem is on average about 150 gigabytes, about 100 times larger than the complete time for a comparable two-dimensional sequence. Usually 350 to 400 of these time steps are saved for a single physics calculation.

One of the largest complete simulations run at Los Alamos used the ASC supercomputer at Lawrence Livermore National Laboratory. This run used an unstructured mesh with a maximum of 468 million cells and saved 21 terabytes of dump data for visualization. As a comparison, the print collection of the Library of Congress contains a total of about 17 terabytes of information. The new immersive room provides a comprehensive visualization infrastructure to do the post-processing analysis of such large amounts of data.



A PROJECT GRID helps Los Alamos researchers perfectly align the projectors. Fakespace built the immersive room to be within 1/30th of an inch accuracy.

Collaboration

A collaborative environment is key to optimum post-processing analysis of these huge datasets, so the labs specified a space where several people could stand comfortably within the immersive environment, with additional observers possible outside the space.

Los Alamos chose a five-sided immersive room over a completely enclosed, six-wall room. The five-sided design, including a rear-projected floor and ceiling, is more comfortable for long periods of use, such as a full day at a time. Five sides provide a sense of immersion without feeling closed in. The open configuration serves well for presentation style reviews with observers facing the immersive room from outside the screen threshold. Having one open side also helps mitigate sound echoes when working in the room. Also, the floor needed to be rear-projected to eliminate the distracting problem of shadows from an overhead projector, and that made it possible to have a projected ceiling as well, which had proved valuable in previously used immersive environments at Los Alamos.

An example of the nominal collaborative process begins when a scientist makes the initial decision to use the capabilities of the DVC. Existing fiber links in every staff member's office are routed to the visualization host computers. Staff with expert visualization skills begin to assist new users in learning the environment and tools, and in integrating software code necessary to generate output data that will be used by the CEI EnSight visualization package, the principal production visualization tool. (ParaView is also supported, and due to its free availability in source code, it is used to prototype new visualization ideas that might subsequently be commercially integrated into EnSight.) Expert staff continue to support the users as needed, frequently assisting in the preparation of formal presentations and new comparative visualization capabilities.

At some point, end-users themselves will gather as team members to begin looking at results and make critical assessments and decisions regarding their simulations. Because the resolution is high everywhere, and because users can "zoom" into their data without constraint, fine details emerge that are not apparent in the office environment. This has shown value both in uncovering previously overlooked simulation errors and bugs, and in gaining new insight into the phenomena being modeled. It is of particular importance to note that, while the actual team use of the large-scale facilities may amount to only a handful of hours or days, the insights gained impact the understanding and subsequent productivity of the staff from that point forward.

Collaboration continues in the next phase of a team's use of the DVC, when it begins using the capabilities to brief critical audiences about the results. The staff have the flexibility to offer both a "canned" version of their findings and, more importantly, to deliver a "working session" interactive briefing to peers, customers and public officials. The audiences gain a sense of participation and control in the discoveries and insights that the team realized in its detailed work. The working session capability has drawn particular note and praise from external reviewers.

COLORS REPRESENT THE AMOUNT of stress on foam that is crushed in a simulation displayed in the Fakespace immersive room at Los Alamos. The simulation was run by Scott Bardenhagen, T-14, LANL. Pictured left to right: Laura Monroe, Katharine Chartrand, Bob Greene, all from Los Alamos National Laboratory, Kent Misegades, CEI, and Bob Tomlinson, LANL.

La Cueva Grande is also part of a larger network of systems, and data viewed there can also be viewed on researchers' desktops, as well as on the other immersive displays at the Nicholas C. Metropolis Center for Modeling and Simulation. The facility also is connected to other national laboratories around the country via a very "fat and secure pipe," for remote collaboration and data sharing, so that calculations made at Lawrence Livermore Laboratory or Sandia National Laboratory also can be visualized at Los Alamos.

Conclusion

As a worldwide leader in the employment of predictive simulation science, Los Alamos National Laboratory is using La Cueva Grande in its primary ASC mission, which again is to maintain the U.S. government nuclear stockpile without underground testing. However, the scientific discoveries that it enables have great future potential for work in crisis prediction, climate modeling, and in understanding the impact of natural and manmade disasters on infrastructure such as transportation, power, telecommunications and water delivery systems.

Because the large-scale visualization environment goes beyond any system in use today, it is an important development in the effort to advance the nature of predictive simulation science, and it is likely to contribute to continued insights in the basic sciences for many years to come. SC

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